Engineering Case Library

ECL 174A

TO FIND A BULLET (A)

"Did you read about that policeman being killed in Berkeley Thursday? Lt. Johnson of the Berkeley police has asked Mr. Mainhardt for help in finding the missing bullet. If you're free I'd like you to go with me to see what we can do for them." This was the call that Jorgen Vindum, an engineer at MBAssociates (MBA) received at his home on Saturday morning, 22 August 1970. The caller was Herb Curtis, Manager of the Applied Products Division.

 Prepared by G. Kardos, Professor of Engineering, Carleton University, Ottawa, Canada with support of the National Science Foundation. The assistance of Mr. Jorgen Vindum and MBAssociates is gratefully acknowledged.

TO FIND A BULLET (A)

Jorgen Vindum had been with MBA since receiving his Master's degree in Aeroscience-Mechanical Engineering from the University of California-Berkeley in 1968. Since joining MBA he had been responsible for several miniature rocket projects and had extensive experience in determining the stability and aerodynamics of rocket trajectories.

For its size, MBA is probably the nation's most advanced technology company. Located 30 miles from San Francisco in the San Ramon Valley, it got its start in 1960 when two nuclear engineers, Mr. Robert Mainhardt and Dr. Arthur Biehl, became interested in miniature rockets and decided to go into business for themselves. For seven years after its founding it remained an R & D company and acquired a highly regarded scientific and engineering team.

Jorgen Vindum indicated to Herb Curtis that he was available and would meet him. He grabbed his slide rule, a protractor and scales, and headed out. He had no idea what to expect. He had seen something in the paper about the shooting but hadn't paid any attention to the details. He presumed that Mr. Mainhardt, the company president, had been called because the police were familiar with MBA due to their close association in the development of MBA's "Stun Gun".

When Curtis and Vindum met the police it was explained to them that Officer Tsukamoto had been killed at 1:00 am Thursday morning, August 20, 1970, (Exhibit A-1) on University Avenue near Jefferson Street in Berkeley.

Witnesses reported that two shots were fired by the assailant. The first shot missed but the second shot hit the officer in the head. The bullet which missed the officer went up the street toward the intersection of McGee. A hunt was started for the bullets in order to determine the kind of weapon used in the shooting.

Later that morning two holes were found in a Chevron sign at the corner of McGee (Exhibit A-2) in line with the scene of the crime. When the alignment of the holes was examined closely the axis of the alignment was found to point to a position approximately twenty feet to the right and nine feet above the firing location. The alignment also indicated that after the bullet left the sign it should have struck the corner of the building across the street from the Chevron station. (Exhibit A-2)

The police hypothesized that the stray bullet had hit a car or some other object and from there deflected through the sign. They also assumed that the bullet had hit the building but they couldn't find the bullet. They searched the area thoroughly but no bullet or sign of the bullet striking an object before or after leaving the sign was found.

At first the MBA representatives could offer no suggestions but they went out to look at the sign. While viewing the sign Vindum postulated that the bullet could be deflected in going through the plastic. If this were the case and the bullet originated at the location of the slaying it would have deflected to the right to strike the back of the sign where it did. If it were again deflected by the back of the sign in the same manner as by the front it could have missed the building.

At this point Curtis and Vindum became really interested because here was something happening that was not obvious to the police which could resolve the puzzle and which could possibly be checked by theory or tests.

Vindum had himself hoisted up in a "cherry picker" and looked through the sign both ways to verify what the police had told him about the alignment of the holes. (Exhibit A-3) While inspecting the sign Vindum made some measurements of angles with a simple rule and protractor. He also received a police sketch of the area showing the sign location and location of fragments of the sign knocked out by the bullet. (Exhibit A-4)

After further discussion Curtis and Vindum decided that Vindum would see what he could deduce from what he had during the remainder of the weekend. They would meet Monday morning bringing in others who might be able to contribute to the solution.

The following Monday Vindum showed Curtis the data he had sketched up on Sunday. (Exhibit A-5) Curtis called a meeting of some of the research and engineering staff members to see if, as a group, they could locate the missing bullet. Among those present besides Curtis and Vindum were: Dr. Raymond E. Lundberg, a staff scientist; Robert Mawhinney, a mechanical engineer; and S. F. Mulich and M. McGill.

Vindum explained the problem. The group then kicked around some ideas. They soon realized that they needed more accurate information than they had at present. The Berkeley police were called and were asked to take pictures of the sign and its location; they were also asked to have the city surveyor meet with MBA representatives to make some measurements.

Mike McGill telephoned Chevron to obtain a sign similar to the one hit by the bullet.

The trajectory of the bullet leaving the sign was no problem. MBA had a computer program they used for computing the trajectory of rockets. The program was two dimensional, based on the mechanics of free flight (Exhibit A-6), but some estimates had to be made of the initial conditions.

On the assumption that the bullet would be deflected in the same manner on leaving the sign as entering it, and assuming the bullet came directly from the point where the officer was killed, Dr. Lundberg constructed a deflection model. (Exhibit A-7)

Still missing was the velocity of the bullet leaving the sign. The muzzle velocity leaving the gun could be estimated by considering the various guns. (Exhibit A-8) But how the velocity was affected by striking the sign was still unknown.

Vindum later recalled "Bob Mawhinney and I were just sitting around and he came up with the idea of energy loss calculations. Since the plastic chips from the sign had gone a fair distance we would estimate the energy lost from the energy in the chips. We needed only a rough estimate to see if we were in the right ball park. We had the location of some of the chips on the map which the police had made. We assumed that the average weight landed half way and worked back to the energy loss." (Exhibit A-9)

Even when the decrease in velocity due to aerodynamic drag before hitting the sign was included, the results showed that although considerable energy was expended in the chips there was still sufficient velocity to carry it well past the building.

There were still many questions unanswered: What kind of bullet was used? Was it smashed by the sign or had it gone straight through? Was the bullet spinning or tumbling? It was decided to run trajectories with a range of values. Dr. Lundberg undertook to run the computer varying each parameter over the possible ranges. These trajectories would not only be useful for the first estimates but once the various parameters were more exactly known the trajectories would be available.

Vindum and Mawhinney went to the Berkeley Chevron station to take pictures, and to see if they could pick up any additional information.

The city surveyor met them and measured the height of the building that the bullet was to have struck. Vindum phoned Dr. Lundberg to get the first computer results. From these it was apparent that the bullet could have cleared the building by a good ten feet. (Exhibit A-10)

Vindum told the police that they had a preliminary model that explained why the bullet had not hit the building. He said that the bullet was somewhere in one of the yards beyond. The policemen's morale was pretty low at this point. This was the first member of the department to be killed. Vindum recalls, "In spite of this, it was just amazing how easy they were to work with. When we told them what we had they were very optimistic. We were leading them in a direction they could understand and which made some sense."

The MBA group were pleased but realized that more accurate data was still required before a reasonable area of search could be determined: The deflection model was still an unproved hypothesis; the velocity loss due to sign penetration was a crude estimate; no data was available on the size and muzzle velocity of the bullet. The bullet had passed over the building and continued on into a heavily built up area.

Vindum and Mawhinney returned to their office pondering how they would resolve these unknowns.

ECL 174A

Oakland Sunday Tribune
A RESPONSIBLE METROPOLITAN NEWSPAPER

YEAR, NO. 235 5CS SUNDAY, AUGUST 23, 1970 35¢ SUNDAY, $3.25 A

Berkeley Spurs Cop Killer Hunt

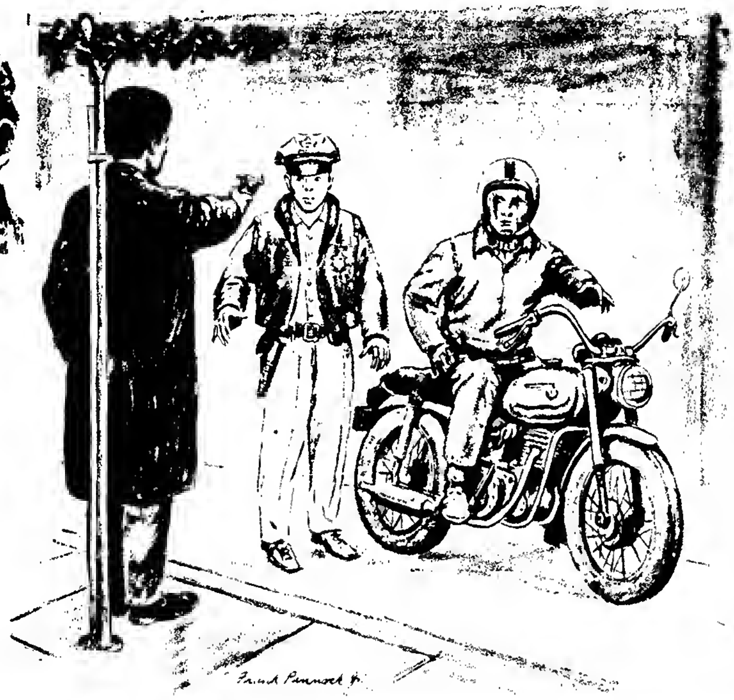
BERKELEY — Police said Saturday night they lacked significant new leads in their search for the gunman who shot patrolman Ronald T Tsukamoto to death on a city street early Thursday.

Efforts to track down a 1959 Studebaker sedan which witnesses said was used as a getaway car have so far proven unsuccessful.

Police said that all available manpower was being used around the clock in the search for the killer. Homicide Inspector Jack Houston reported a task force is carefully following up every new bit

See Back Page, Col. 7

SKETCH OF SLAYER
Suspect still at large



Tribune drawing by Frank Pennock

Slim Leads In Hunt for Cop Killer

Continued from Page 1

of evidence but "We still don't know who the man is."

Tsukamoto, 28, a rookie officer, died Thursday after he was shot in the head by a man who walked up after the officer had stopped a motorcyclist for making an illegal U-turn.

The shooting has been termed a political act by Police Chief Bruce Baker who added, "The seeds of revolution have been sown and now they are reaping the harvest."

Tsukamoto, like two other Bay Area police officers killed recently, was on solo patrol.

In San Jose, Police Chief Ray Blackmore announced following Tsukamoto's death that two man patrol cars will be on the streets from nnw on at night.

A San Jose patrolman, Richard Huerta, was shot to death earlier this month as he was writing out a traffic ticket.

Police are carefully guarding the identity of the young motorcyclist stopped by Tsukamoto, who had the opportunity to view the gunman at close range.

The witness described a composite drawing of the suspect as "somewhat similar" to the killer but not an exact rendition

The cyclist said Friday that he thought he could identify the man if he saw him again.

He said when the man first approached officer Tsukamoto he was friendly and engaged the policeman in small talk for a short time before suddenly pulling a revolver and firing twice.

"The last time I saw him (the gunman) he was at the corner heading down Jefferson," said the witness. "I didn't see him after that."

Police Chief Bruce R. Baker said Thursday he believes there was another person in the getaway car in which the gunman fled. The man got in the passenger's side of the auto, said Baker, and, according to witnesses, the motor was running

So far neither of the two bullets fired has been found.

Death Scene Re-created

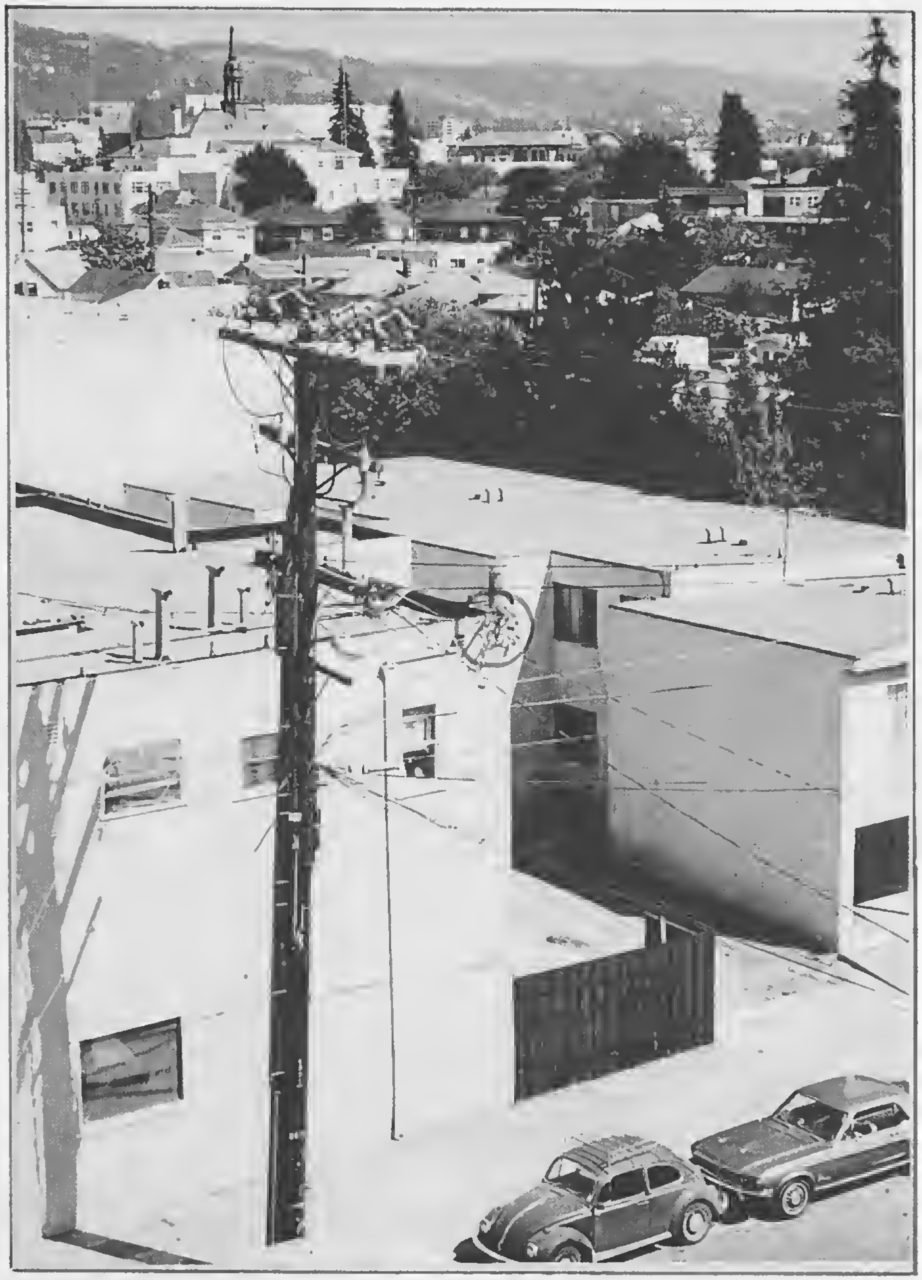
His arm raised, the gun in his hand pointed at the head of Ronald Tsukamoto, the slayer of the rookie Berkeley patrolman is shown (above) in an artist's re-creation of the scene just before the trigger was pulled in slaying early last Thursday. Still seated on his motorcycle is a witness, the young man whom Tsukamoto stopped for making an illegal U-turn. The drawing, to protect the identity of the witness, was made from a photograph of a reconstruction of the crime. Another photograph taken at the scene after the shooting shows the motorcycle (above) as it was left by the young man when he ran to call police.

EXHIBIT A-1

View of Corner, McGee & University Avenues
Facing East

Close-Up of Chevron Sign

EXHIBIT A-2



Looking Over Top of the Sign Away from the Scene of the Crime. Circle Shows View Through Holes.

Looking Through the Bullet Holes Away from the Scene of the Crime

EXHIBIT A-3

ECL 174A

6 / D

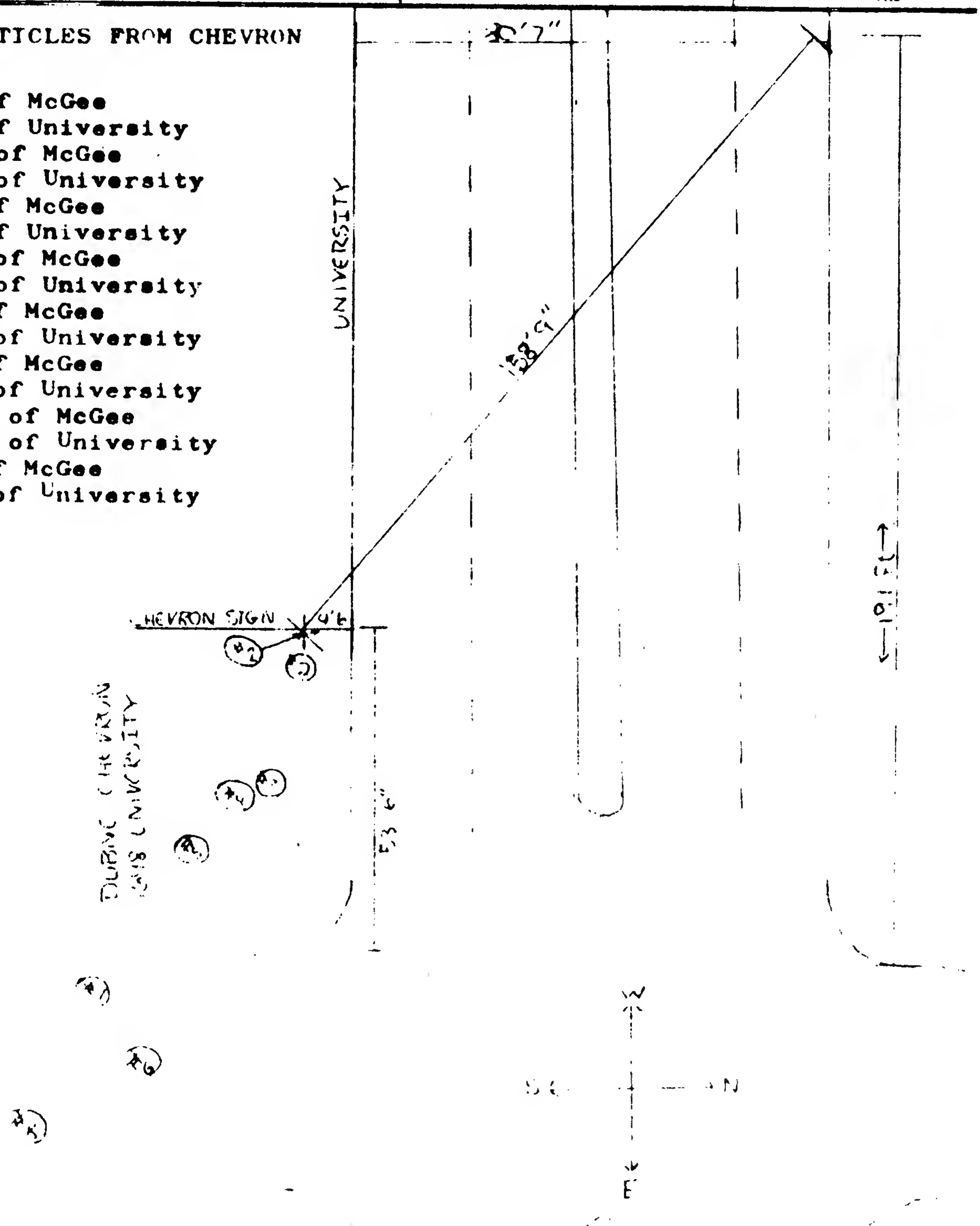
ERKELEY POLICE DEPARTMENT
INCIDENT DIAGRAM

NO. W-19883

LOCATION OF INCIDENT UNIVERSITY AND JEFFERSON	DATE & TIME 8 20 70, 10 53AM	PHOTOGRAPHS [ ] YES [X] NO

POSITION OF PARTICLES FROM CHEVRON SIGN.

1. 53'6" west of McGee
   1'2" south of University
2. 51'10" west of McGee
   7'11" south of University
3. 23'7" west of McGee
   9'0" south of University
4. 21'10" west of McGee
   11'6" south of University
5. 18'9" west of McGee
   17'3" south of University
6. 15'5" east of McGee
   21'4" south of University
7. 8'3 3/4" east of McGee
   24' 8" south of University
8. 21'9" east of McGee
   32'2" south of University



Prepared by N.A. MARQUART

No. 117

Date and Time 8-20-70, 10:55AM

Form 314-736

EXHIBIT A-4

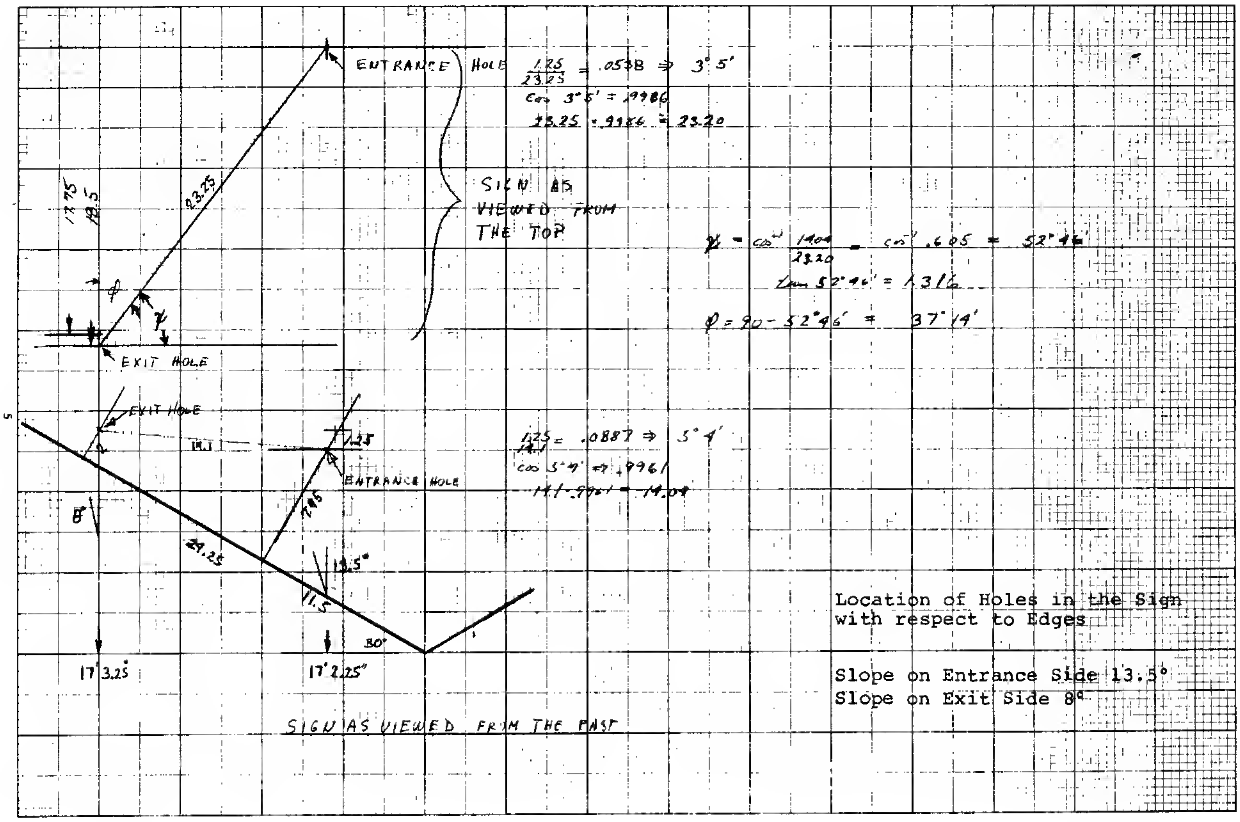


FIGURE 1

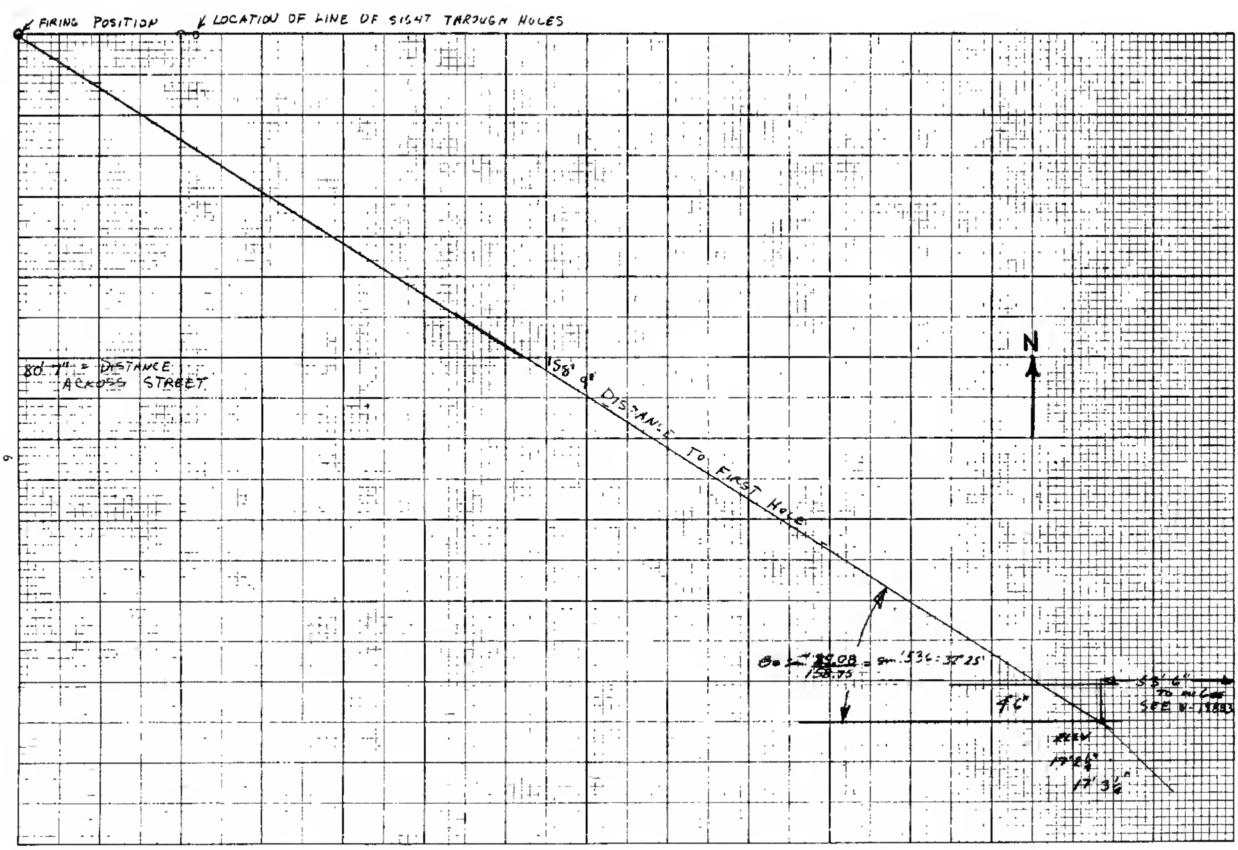
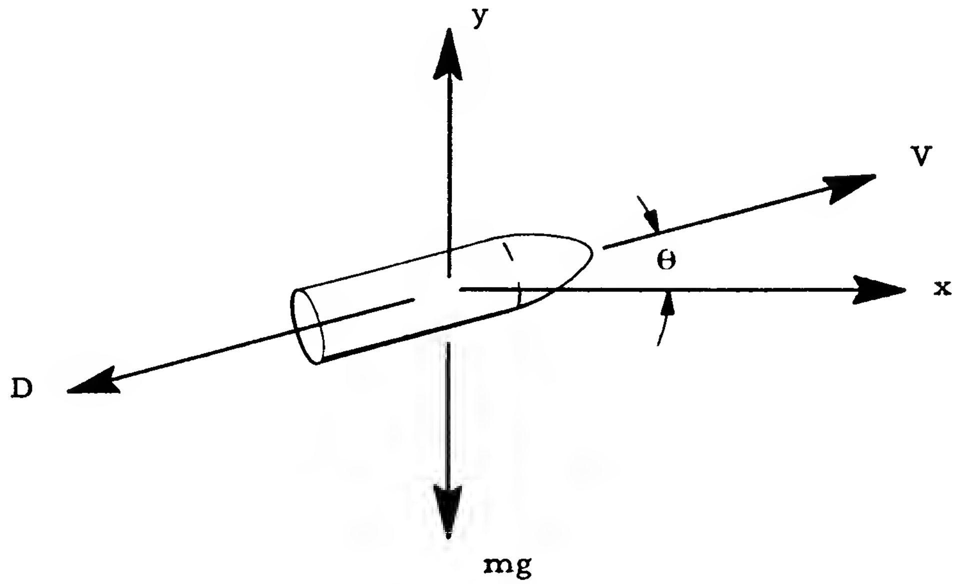


FIGURE 2

EXHIBIT A-5

Trajectory Calculations (From MBA Final Report)

The equations of motion that determine the trajectory of a projectile are derived as follows:



From $\Sigma F = ma$

$$m\frac{d^2y}{dt^2} = -\frac{1}{2} C_D \rho A \left(\left(\frac{dy}{dt}\right)^2 + \left(\frac{dx}{dt}\right)^2\right) \sin\theta - mg$$

$$m\frac{d^2x}{dt^2} = -\frac{1}{2} C_D \rho A \left(\left(\frac{dy}{dt}\right)^2 + \left(\frac{dx}{dt}\right)^2\right) \cos\theta$$

where $\theta = \tan^{-1} \frac{\left(\frac{dy}{dt}\right)}{\left(\frac{dx}{dt}\right)}$

also from initial conditions at $t = t_o$

$$\left.\frac{dy}{dt}\right|_o = V_o \sin\theta_o$$

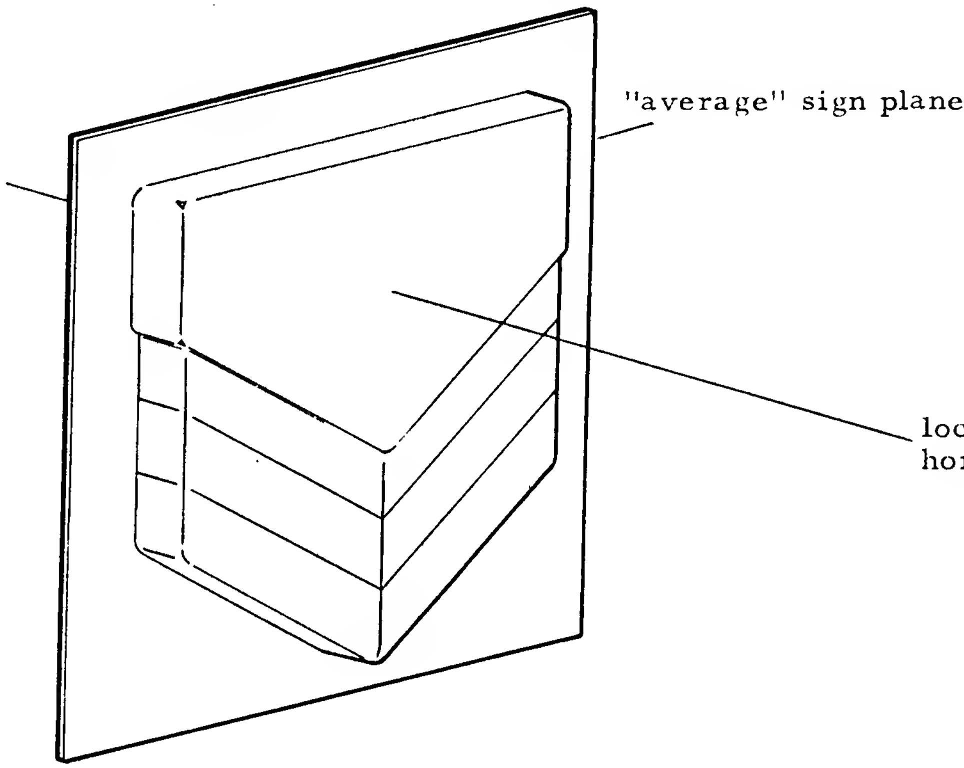
$$\left.\frac{dx}{dt}\right|_o = V_o \cos\theta_o$$

m	=	mass of projectile
y	=	vertical coordinate
x	=	horizontal coordinate
C_D	=	drag coefficient
ρ	=	air density
A	=	frontal area of projectile
θ	=	flight angle
g	=	accelleration due to gravity
V_o	=	muzzle velocity
θ_o	=	muzzle angle

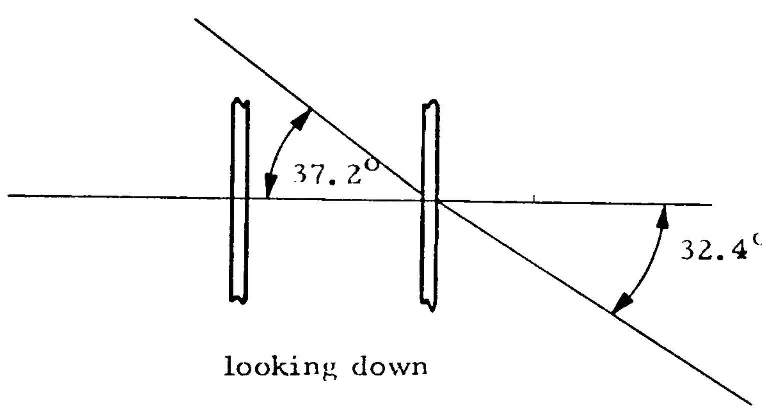
EXHIBIT A-6

Deflection Model (From MBA Final Report)

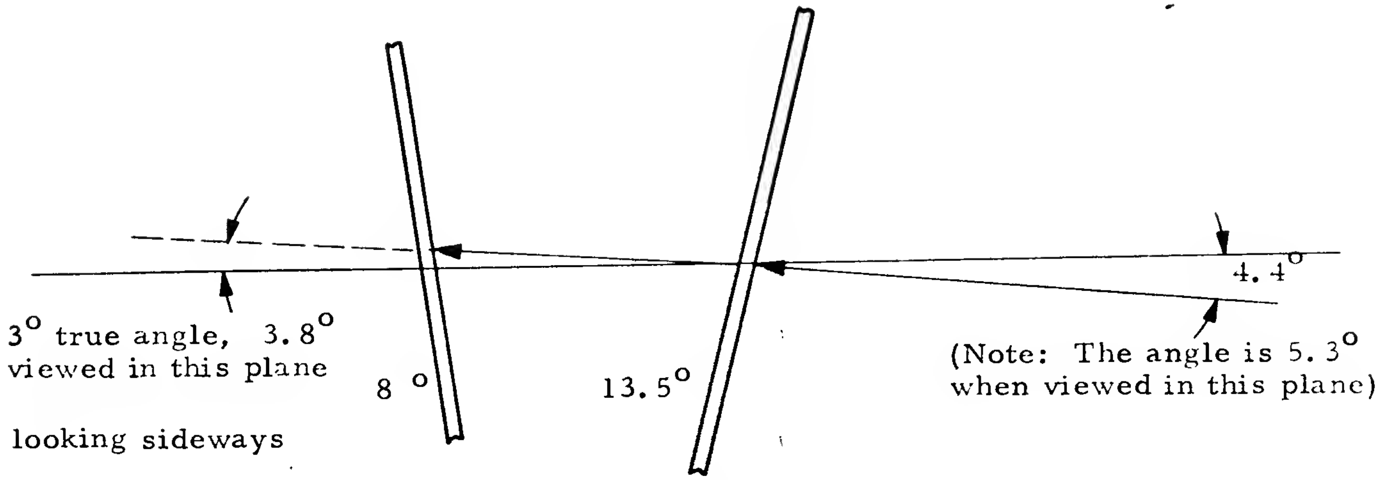
On striking the plastic sign at an angle the projectile deflects due to both normal and frictional forces. Based on the entrance and exit hole positions and a knowledge of the firing angle we can estimate the exit angle from the sign. Let us reference all the angles to a local horizontal line perpendicular to the average plane of the sign.



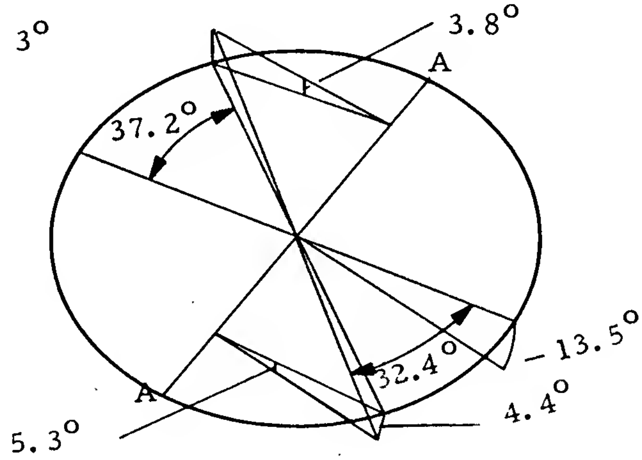
The bullet entered the front face at an angle of 32.4° with the horizontal and inclined upward at 4.4°. The front face of the sign where the bullet struck is perpendicular to a vertical plane containing the reference line but tilts downward 13.5°.



looking down



After passing through the front surface the bullet angle was 37.2° to the horizontal, and 3° to the vertical as determined by measurement and surveying. The local surface normal is used as a reference.



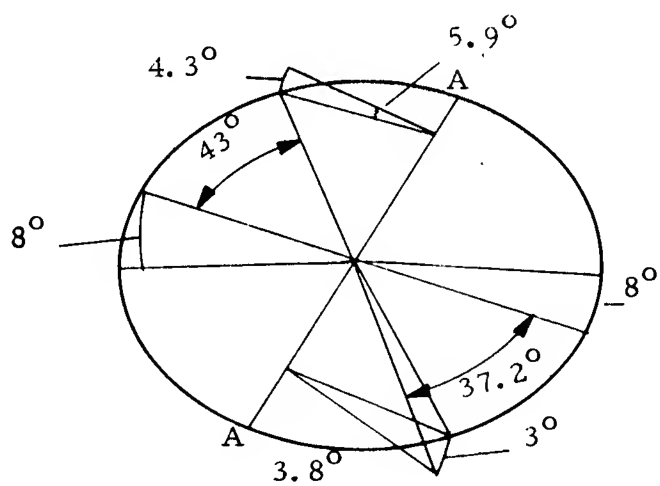
Using an accepted technique of vector analysis the horizontal and vertical deflections are separated.

We then assume that there deflections can be treated separately. The plane passing through A-A and containing the entering bullet vector makes an angle with the plane passing through A-A and containing the vector normal to the surface of 13.5° -5.3° = 8.2°. On exit from the first surface this angle is 13.5° - 3.8° = 9.7°.

Then if the change of the vertical component of bullet velocity is viewed as a rotation of the plane containing the bullet about A-A, that plane was deflected away from the surface normal with the ratio of the angles $\frac{9.7}{8.2} = 1.18$

The horizontal component is also deflected away from the normal with the ratio of angles being 1.14. (The closeness of the two turning ratios is encouraging.)

Let us assume that the same ratio of entering and leaving flight angles holds on passing through the rear surface. With this assumption the relationship between the bullet path and the rear surface can be constructed as follows. The rear sign surface tilts 8^{o} downward relative to the local horizontal



so a vector diagram becomes as illustrated. The tilt of the plane containing the bullet vector and passing through A-A is increased to $11.8 \times 1.18 = 13.9^{o}$. The exit horizontal angle should be $1.14 \times 37.2 = 42.5^{o}$. From the vector diagram the bullet vector relative to the reference line is about 43^{o} bearing and 4^{o} to 5^{o} vertical angle.

Characteristics of Various Projectiles and Barrels

Cartridge	Bullet Grs.	Bullet Style	Muzzle Velocity	Muzzle Energy	Barrel Inches
38 S&W Blank (c)	No Bullet		-	-	-
38 S&W	146	Lead	685	150	4
38 S&W (a)	146	Lead	730	172	4
38 MK II (a)	180	MC	620	153	5
38 Special Blank (c)	No Bullet		-	-	-
38 Special, IL (c)	150	Lub.	1060	375	6
38 Special, IL (c)	150	MC	1060	375	6
38 Special	158	Lead	855	256	6
38 Special	200	Lead	730	236	6
38 Special	158	MP	855	256	6
38 Special WC (b)	148	Lead	770	195	6
38 Special Match, IL(c)*	148	Lead	770	195	6
38 Special Match, IL(b,c)*	158	Lead	855	256	6
38 Special Hi-Speed	158	Lead	1090	425	6
38 Special (a)	158	RN	900	320	6
38 Colt New Police	150	Lead	680	154	4
38 Short Colt	125	Lead	730	150	6
38 Short Colt, Greased(c)	130	Lub.	730	155	6
38 Long Colt	150	Lead	730	175	6
38 Super Auto (b)	130	MC	1280	475	5
38 Auto, for Colt 38 Super (c)	130	MC	1280	475	5
38 Auto	130	MC	1040	312	4-1/2
380 Auto	95	MC	955	192	3-3/4
38-40 Winchester	180	SP	975	380	5

EXHIBIT A-8

Preliminary Estimate of Velocity of Bullet Beyond Sign

From the positions where the plastic chips were found, the velocity can be estimated to be approximately 125 ft/sec.

$$\text{Kinetic Energy of Plastic on back side} = \frac{1}{2} MV^2$$

$$KE = \frac{1}{2} \quad \frac{.019}{32.2} \quad x \quad (125)^2 \quad = \quad 45 \text{ ft lb}$$

This value is doubled to include the front side and the breaking energy of the plastic added to give the total energy approximately equal to 100 ft-lb. For a 158 grain bullet travelling at 700 ft/sec the KE = 140 ft-lb. Subtracting the 100 ft-lb penetration energy leaves 40 ft-lb which is equivalant to the bullet travelling $\sim$350 ft/sec.

Preliminary Estimate of Bullet Velocity Loss Due to Aerodynamic Drag Before Hitting the Sign

$$\lambda = 1500$$

$$V = \frac{V_{BO}\ \lambda}{\lambda + V_{BO}\ (t - t_{BO})}$$

$$V = \frac{700 \times 1500}{1500 + 700\ \frac{160}{700}}$$

$$V_{BO} = 700$$

$$\text{dist} = 160$$

$$t - t_{BO} = \frac{160}{700}$$

$$V_{impact} = \frac{700 \times 1500}{1660} = 632 \text{ ft/sec.}$$

A reduction of 70 ft/sec prior to hitting the sign was not considered important to the preliminary computations.

λ = slowing down distance = 1500
or the distance in which a projectile loses 1/e its velocity

V = velocity at impact

V_{BO} = velocity at muzzle = 700 ft/sec

EXHIBIT A-9

T = tumbling

S = spinning

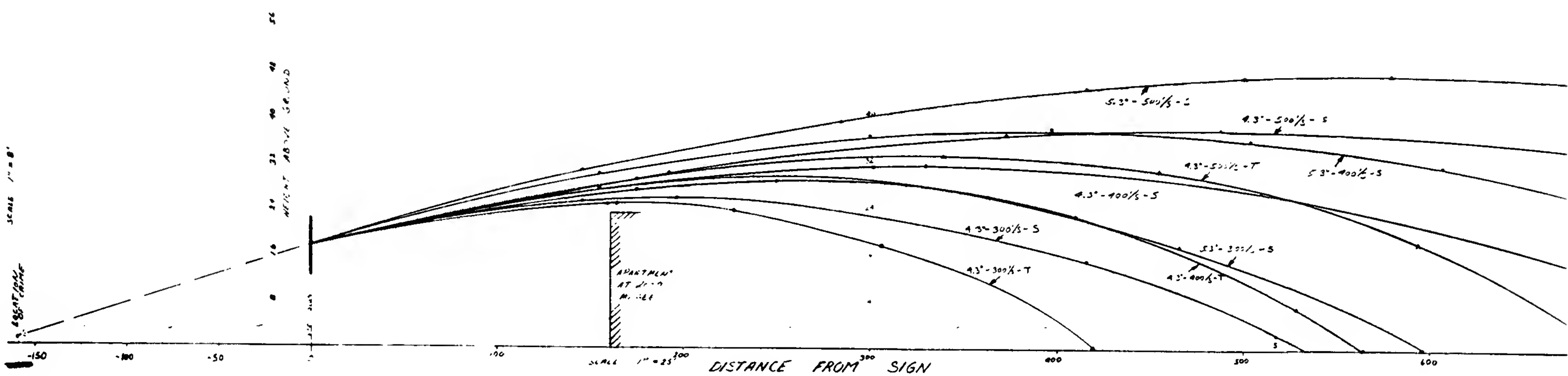


EXHIBIT A-10

ECL 174A

TO FIND A BULLET (B)

Before returning to MBA Vindum and Mawhinney talked to the city surveyor. By this time he had become deeply interested in the project. They explained to him that they wanted a topographic map of the city area along the possible flight of the bullet; they needed the location and height of the buildings. The surveyor promised to make the necessary measurements and to prepare a map.

They questioned the police further on the possible weapon that may have been used in the killing. The witnesses who had seen the shooting said that the weapon was a revolver with a short barrel, probably 2". The police believed it must have been a .38 caliber since this was the most common size. The police suspected that it was a low velocity bullet coming from a 2" barrel. The bullet couldn't have been a .22. If it had the bullet would have stopped in the head. Neither could it have been one of the more powerful bullets that the police use because that would have blown the back of the head off. The characteristics of .38 projectiles and barrels are all approximately the same and correspond to that which was used in the computer program.

As to the type of bullet, the police said it could have been one of many types: plain lead, copper jacket with steel inside, copper jacket with lead inside, and half jacketed bullets. Since there was no trace of lead in the victim's skull the police ruled out a solid lead bullet.

When Vindum and Mawhinney returned to MBA they got together with Lundberg who had completed the trajectory runs. Some of these results were eventually plotted. (Exhibit B-1) They discussed what should be done next. Since McGill had been promised a Chevron sign, they decided that some tests should be carried out to prove their deflection model. Maximum information could best be obtained by duplicating actual conditions. It was agreed that Jorgen Vindum would continue to carry out the investigation with the others contributing when and where they could.

The sign arrived on Tuesday and was set up with the plastic half shells of the sign mounted in a normal manner. The mounted sign was placed in front of a deflection witness board made of Celotex. A photo grid having one foot squares was located to the right of the sign. Two high speed cameras were located to the left. (Exhibit B-2)

On Wednesday Vindum asked the Berkeley police to come down for firing tests. The police were to bring a variety of bullets and two different revolvers, a Smith and Wesson, and a Colt: one having a right hand rifling, the other a left hand rifling. The hole in the plastic sign had rays running from it and they were twisted. It was hoped that this twist might give some clue as to the type of pistol used. (Exhibit B-3)

In addition to the standard loads Vindum asked the police to bring shells with the powder charge reduced by 10%. If the deflection was sensitive to velocity of impact, this would reproduce the lower velocity of the bullet because of the aerodynamic drag between the scene of the crime and the sign.

A firing point was set up 20 feet in front of the sign and a post was set in the ground with a marker to indicate where the revolver was to be held when firing. (Exhibit B-2) A mark was made on the sign as a target. It was important that the sign be hit at the same angle as in the shooting. The marksmanship was excellent. (Exhibit B-3)

Vindum recalled how the technique developed, "The first thing we intended to do was to duplicate the hole size and shape. We didn't know for sure that different bullets left different holes. After we shot a few it was quite obvious that you could narrow down the choice of bullet by the type of hole in the sign.

"We put up the Celotex behind the sign to see which direction the bullets came out and to check our deflection model. It turned out that some bullets observed our deflection model very accurately, others would not. The ones which did not followed the model generally but deviated from it in a random fashion.

"It turned out that if the bullet kept spinning after poking through the front of the sign it would behave in an identical manner when striking the back face, whereas, something like a lead bullet gets smashed going through the front face and starts tumbling and will not strike the back face in an identical manner. It therefore comes out randomly."

The results of the tests (Exhibit B-4) narrowed the type of bullet down to three possible types: the half jacket, the lead bullet, and a full jacket with lead inside. These penetrated the front of the sign leaving a hole similar to that at the scene of the killing. The bullets were mashed and left a very jagged hole in exiting the back side of the sign. Unfortunately this

meant that the acutal bullet left the sign in somewhat random manner and therefore would be more difficult to find.

Vindum explained it this way: "They all kind of followed our model but they deviated in a more or less random manner by a few degrees because of tumbling. The bullet would usually come out at a smaller angle then the model. It seemed more likely to come out to the left of the expected line. I didn't have much to base this on except having seen where they came out, I had sort of a feel. We ran strings from the exit holes to the corresponding holes in the witness board to get a feel for the angles. I felt that the highest probability was that it would deviate from five degrees to the right to ten degrees to the left of our model."

Unfortunately the attempt to measure velocity with the high speed camera was not successful. Pictures of the flight between the signs were obtained but they were not good enough to be of any use. One of the MBA technicians then suggested making chronographs. These consisted of two sheets of aluminum foil separated by a plastic film and mounted on a wooden frame. With a potential across the aluminum foil and properly connected to a recorder, the bullet would short circuit the aluminum foil when passing through. This would give an indication on the recorder. Using four screens suitably spaced the recording could be used to determine the velocities.

On Thursday they had the police return for further firing tests. This time they restricted the firings to the half jacket lead core and the full jacket bullets. (Exhibit B-4) The chronographs measured the velocity before, between, and after leaving the sign. (Exhibit B-5) The chronographs worked well. They were not fool proof but as Vindum said, "I was quite satisfied; I felt we had something like 60%-75% reliability. We were not limited by the number of bullets. We were going to shoot until we got our answers sooner or later". The deflection pattern was also observed as before and confirmed the previous estimates of random scatter.

The velocity measured was somewhat higher than initially predicted by the chip model. But when corrected for velocity loss from firing point to sign, the parametric model was justified.

With the test completed Vindum called the city engineers for the promised topographic map. They had just completed the necessary survey and promised him the map the next day. (Exhibit B-6)

On Friday, Vindum looked at the map and reviewed the information he now had available: "The solid line going down the center of the impact area is the line we get from the deflection model, a 10 degree 42 minute deflection to the right of the original line of fire. From firing tests the bullet is more likely to be to the left of this line, say 10°, than to the right, although it could go to the right, say 5°. Besides, if it had gone further left it would have hit the corner of the 31.7 ft. high building on the corner of McGee and University Avenue, and they have already searched the alley there."

"From our firing tests the bullet was probably tumbling. Although we have a velocity figure we will have to put on some upper and lower bounds. Initially let's say that the vertical angle varies plus or minus one degree.

"The bullet will have to go through the wooded lot behind 2009 McGee. I know that quite massive objects can be deflected by small branches, therefore, it might have fallen into one of these back yards.

"With this map and the trajectories (Exhibit B-1), I should be able to sketch out a reasonable area of search."

T = tumbling

S = spinning

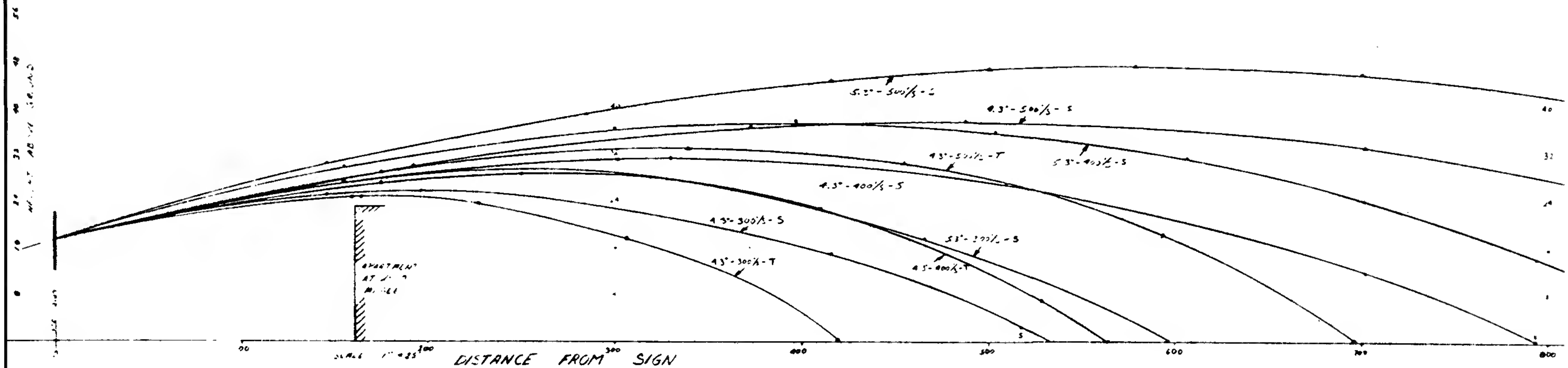
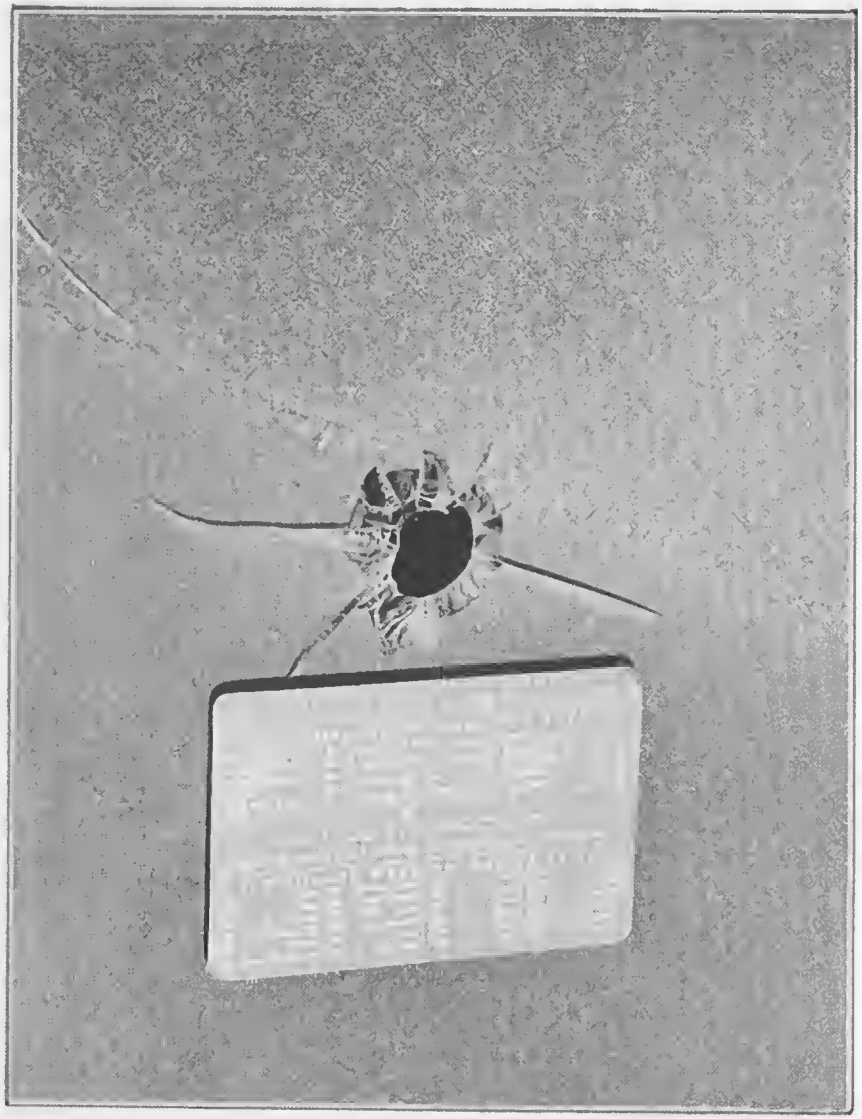


EXHIBIT B-1

ECL 174B

Test Showing Shooter Position

EXHIBIT B-2



Entry Hole in Berkeley Chevron Sign

Entry Hole of Lead Projectile

EXHIBIT B-3

Sign Penetration Tests - Wednesday, August 26, 1970

	Projectile Wt.	Jacket Type	Case Type	% Powder Load	Gun Type
1.	158 grains	Full	Steel	90%	2" S&W
2.	158 grains	Full	Steel	90%	2" Colt
3.	158 grains	None	Lead	90%	2" S&W
4.	158 grains	None	Lead	100%	2" S&W
5.	150 grains	Armor Piercing	Lead	100%	2" S&W
6.	150 grains	Armor Piercing	Lead	90%	2" S&W
7.	158 grains	Half	Lead	80%	2" S&W
8.	158 grains	Half	Lead	100%	2" S&W
9.	158 grains	Half	Lead	90%	2" S&W
10.	158 grains	Full	Steel	80%	2" S&W

Sign Penetration Test - Thursday, August 27, 1970

All except 19 and 20 were half jacket, lead core, 158 grain projectiles. 19 and 20 were MIL 66 full jacket.

	% Powder Load	Gun Type	Powder Type
11	100%	2" S & W	"Factory"
12	100%	2" S & W	"Factory"
13	100%	2" S & W	"Factory"
14	100%	2" S & W	"Factory"
15	100%	2" Colt	"Factory"
16	100%	2" Colt	"Factory"
17	90%	2" Colt	4.8 unique
18	90%	2" Colt	5. unique
19	100%	2" S & W	"Factory"
20	100%	2" S & W	"Factory"

EXHIBIT B-4

Velocity Measurements made on Shots 11 through 15

	Velocity Before Sign	Velocity Between Sign	Velocity Behind Sign
11	-	→ 493 ft/sec	(AVE) ←
12	-	479	407
13	-	645	398
14	707	515	389
15	727	618	518

Comparison of Preliminary Parametric Model with Test Results

	Assumed	Test Results	Comments
Velocity of Bullet	700	712	Average of 2
Velocity loss through sign - both surfaces	250	285	Sum of 2 averages
Exit Velocity	350	357*	

* This figure has been reduced 70 ft/sec as the correction for velocity loss from the firing point to the impact point due to aerodynamic drag. The method of Appendix C was used to develop this value.

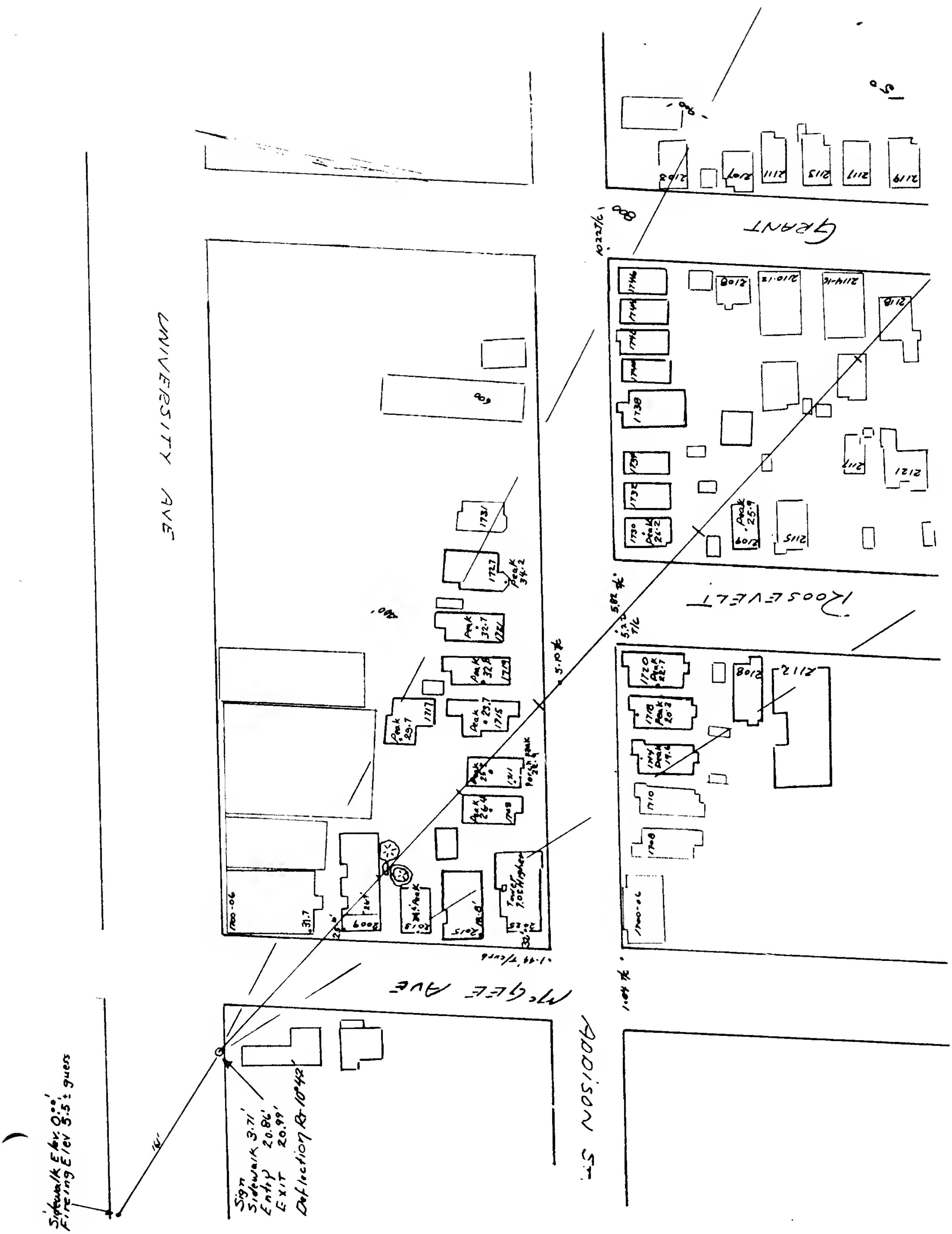

UNIVERSITY AVE
McGEE AVE
ADDISON ST
GRANT
ROOSEVELT
Sidewalk Elev 0.0'
Firing Elev 5.5' ± guess
Sign
Sidewalk 3.71'
Entry 20.86'
EXIT 20.99'
Deflection Rt 10°42'

EXHIBIT B-6

EXHIBIT B-7

TO FIND A BULLET (C)

Jorgen Vindum tells how he used the computer trajectories and the test data to sketch the search area for the police. (Exhibit C-1)

"There was nothing magic in what I did. Anyone at MBA could have done it. I just happened to be the one assigned to the project. As you can see on the map (Exhibit B-5) that solid line down the center is the line we get from the deflection model, 10° 42' to the right of the line of fire. The bullet was unlikely to be to the right. We had a pretty good feel for this from the tests. It was much more likely to be to the left. Therefore, I arbitrarily took five degrees to the right and ten degrees to the left. I also felt that this was a practical limit for the search.

"Since we knew that the bullet was tumbling, we only needed half the trajectories computed. We just took a lower and upper bound from these trajectories. I used test velocities as the average and added plus or minus 50 ft/sec for the upper and lower bounds, then assumed plus and minus one degree on the trajectory angle of 4.3°.

"The funny shape we got for the impact area was due to the houses shielding part of the ground. There was no use searching there. The shielding was determined simply by sketching buildings on the trajectory plot and finding how far out the bullet could land if it just cleared the building. There were two possible areas: the furthest out was the most likely area and a second area closer to the sign where the bullet might have landed if it hit the tree and was slowed down.

"On Friday I called the police and told them to pick up the map. We wouldn't guarantee anything but if they were willing to spend the time searching, this would be the best area to search. (See Exhibit C-2)

"There was a lot of luck in finding the bullet. You can see that where it was found, at Addison Street, is more than 5° off the center line. If we had not gone to 10° to the left we would have missed it. The bullet was in bad shape. It had been run over by tires several times."

The location in which the bullet was found is shown in Exhibit C-1.

ECL 174C

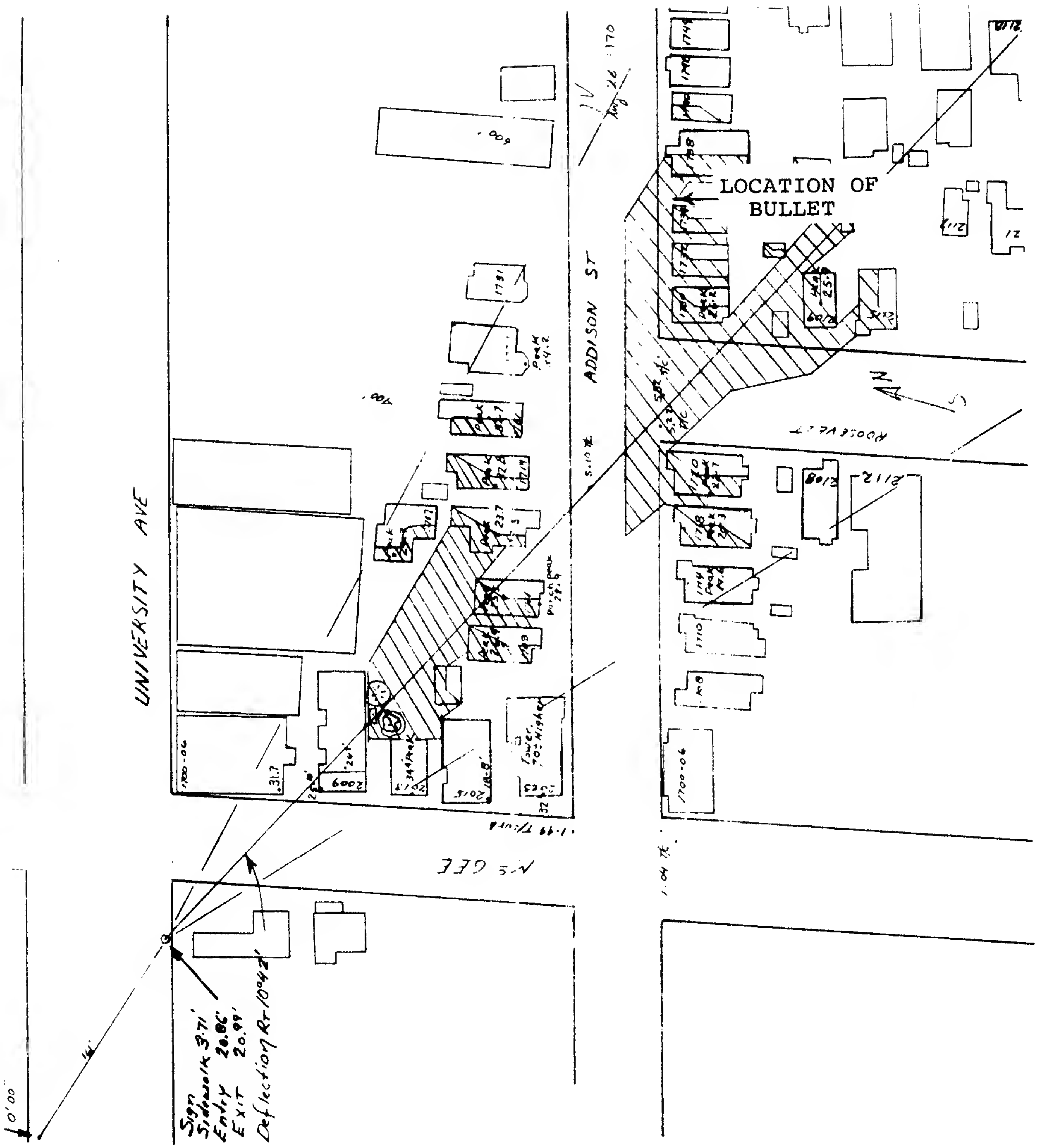


EXHIBIT C-1

San Francisco Chronicle

106th Year No. 246 HOME EDITION ** Monday, Sept. 7, 1970 10 CENTS GArfield 1-1111

How Computer Traced a Bullet

By Charles Raudebaugh

Berkeley police and M.B. Associates, a rocket manufacturing firm in San Ramon, each bowed to the other last week to give credit for what may be the first use of a computer in a murder case.

Berkeley police said it was MBA's idea to use its sophisticated laboratory facilities to find a bullet from the gun that killed Officer Ronald Tsukamoto two weeks ago, while MBA said the police thought of it.

However the idea originated, it marked a new step in criminology in the west, if not in the nation.

VITAL

And, regardless of who gets the credit, a battered bullet that may play a vital role in the eventual solution of Officer Tsukamoto's murder is now being studied in the crime lab of the State Bureau of Criminal Identification and Investigation at Sacramento.

It was found in a driveway a block away from the scene of the officer's shooting and in the area where the computer said it would be found.

In fact, the computer data was so accurate that the bullet was picked up by an officer who went to the area to tell residents that searching teams of police would be around shortly.

FIRED

The bullet was the first of two fired at Officer Tsukamoto about 1 a.m. on August 20 as he was lecturing a motorcyclist who had made an illegal U-turn on University Avenue. The second bullet went into his brain.

When daylight came, police found that Bullet No. 1 had ripped through a service station sign 160 feet from the spot where the policeman was slain.

The sign was 18 feet in the air, and from visual inspection it appeared to police that the bullet had probably struck a nearby apartment building and spun off. But the building showed no bullet mark and there the trail ended — until MBA engineers moved in two days later.

PLASTIC

"The sign was composed of two pieces of plastic about 22 inches apart, and measurements in great detail showed the course of the bullet was altered by the first surface and thereby would be altered further by the second surface," said an engineer, who asked that his name be withheld.

"Our preliminary calculations showed that the bullet would miss the apartment building.

"So we obtained a duplicate sign and using bullets of various calibers and power — we had nothing precise to go on — we test-fired bullets through the sign.

"Altogether, we tested six different bullets, compared the holes in the test sign with the original sign. We also measured the velocities of the bullets coming out of the back of the sign

TEST

"We used two methods of measurement. One was high speed photography — pictures at 3000 frames per second — and an electric field through which the test bullets passed.

"So we had both the angle and the velocities. Then the Berkeley City engineer's office gave us some special maps showing the elevation of all buildings in the area.

"We fed it all into the computer. It was not a difficult computer problem at all."

The computer came up with three likely areas in which the bullet could be found.

PRIME

Prime Recovery Area was a roughly-triangle shaped area about 75 feet wide and 240 feet long a block away, diagonally, behind the service station

The other possible recovery areas were predicated upon the possibility that the bullet had been deflected by a fir tree 35 feet high. Some of the test trajectories would not have cleared the tree.

The firing and field testing took several days but the computer had its answer in a few minutes.

SEARCH

The search was set for Saturday morning, August 29.

Officer Carl Lipgens was assigned to precede the search team and notify residents of the Prime Recovery Area not to be alarmed if they saw a lot of officers.

He had just left the household at 1734 Addison street when he spotted the bullet on a concrete driveway, between the sidewalk and the street.

It lay 620 feet beyond the service station sign, and a total of 780 feet from the spot the murderer stood.

EXHIBIT C-2

INSTRUCTOR'S NOTE

To Find a Bullet

This case tells of an unusual application of the engineering method, the location of a missing bullet in a police case. The construction of the case is to show and to lead the student through the solution as carried out by Jorgen Vindum, the principal investigator. The case is divided into three parts; each section ends at a critical decision point and students can be asked to discuss the course of action to be followed. The case involves a mixture of technology, computer application, intuition, experimentation, logical thinking and plain luck.

The first part of the case telling of the problem given Vindum and of the shooting incident can be assigned for reading and discussion. All the facts are given so that the student can discuss and verify the postulates made by Vindum of the deflection model, the bullet velocity beyond the sign and the trajectory. The conformation of the deflection model makes an interesting descriptive geometry problem, and can only be understood with careful study. The trajectory calculations are simple although they are presented in differential form. They can be used as a motivation for an exercise in computer programming. The ending provides for class discussion on the course of action: are the models reliable? what testing should be done to confirm them? what should be the purpose of the tests? how will the test results be used?

The second part of the case tells of the test program carried out by MBA and gives the results. Discussion in class can be focused on: were the tests the best that could be carried out? what other tests should be done? what conclusions can be drawn from the tests? were the conclusions drawn valid? The inclusion of the topographical map and the computer trajectories can be used for assignment to have the students generate the necessary search area.

The final part of the case gives Vindum's solution to the search problem and by way of a newspaper clipping reports on the successful location of a bullet. Class discussion can be used to: assess the merits of Vindum's search area and compare it with that generated by the students; discuss Vindum's method of arriving at the search area. The entire case can then be reviewed to examine the part that science, computers, logic, intuition and luck played in the solution of the problem and to speculate if this is typical in engineering.

Xerox copies of computer printout of trajectories are available for $2.00 from the Engineering Case Program.